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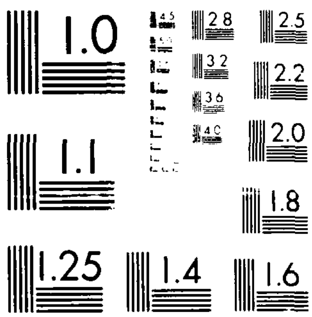
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NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

A MODEL OF THE EFFECT OF SPARING AND REPAIR TURNAROUND TIME OF THE INERTIAL NAVIGATION SYSTEM ON AIRCRAFT READINESS FOR THE F/A-18

by

Christopher A. Hase

June 1988

Thesis Advisor Alan W. McMasters

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Modern aircraft design allows for short turnaround times by removing the failed component and installing an operational one. The defective component is then either repaired in the squadron or turned in to supply which then sends the defective component to an Intermediate Maintenance Activity (IMA) for repair. The aircraft is unable to be turned around for another flight if supply is out of stock of that component without resorting to additional maintenance measures. This is when aircraft readiness experiences a measurable deterioration due to supply not having the part on hand. Aircraft readiness, as defined in this thesis, is the ability of a specific F/A-18 to perform all of its missions. A simulation model which measures the time that an aircraft is not ready (downtime) was developed to relate the turnaround time at the IMA and the quantity of spare parts maintained by the supply system to this lack of readiness. The model developed showed that a decrease in the turnaround time of a part at the IMA, the increase in quantity of spare parts maintained by the supply system cause a nonlinear reduction in aircraft readiness. This model could be used to aid decision makers in determining the effect changes in spare parts quantities and IMA turnaround times could have on aircraft readiness.

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A Model of the Effect of Sparing and Repair Turnaround Time of the Inertial Navigation System on Aircraft Readiness for the F/A-18

by

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Submitted in partial fulfillment of the
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ABSTRACT

Modern aircraft design allows for short turnaround times by removing the failed component and installing an operational one. The defective component is then either repaired in the squadron or turned in to supply which then sends the defective component to an Intermediate Maintenance Activity (IMA) for repair. The aircraft is unable to be turned around for another flight if supply is out of stock of that component without resorting to additional maintenance measures. This is when aircraft readiness experiences a measurable deterioration due to supply not having the part on hand. Aircraft readiness, as defined in this thesis, is the ability of a specific F/A-18 to perform all of its missions. A simulation model which measures the time that an aircraft is not ready (downtime) was developed to relate the turnaround time at the IMA and the quantity of spare parts maintained by the supply system to this lack of readiness. The model developed showed that a decrease in the turnaround time of a part at the IMA, the increase in quantity of spare parts maintained by the supply system cause a nonlinear reduction in aircraft readiness. This model could be used to aid decision makers in determining the effect changes in spare parts quantities and IMA turnaround times could have on aircraft readiness.

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I. INTRODUCTION

A. OVERVIEW

Readiness is the ability of a system to respond to external factors and is measured by the length of time it takes to make that response. Readiness is one of the pillars today s Navy is built on. This study was done to determine some of the factors that affect the readiness in aircraft.

Readiness is a design characteristic built into the Navy's aircraft. This is achieved primarily by allowing malfunctioning systems to be easily identified, removed and replaced. This concept works so well that sometimes this entire process can be accomplished just minutes prior to an aircraft taking off. A critical factor allowing this high state of readiness to be a reality is having the part when it is needed. The Navy's approach is to store the spare parts and to repair the failed parts as close to the flight line as possible. Navy policy determines the composition of spare parts carried as well as the capability to repair those parts.

The Navy spends considerable time and money dealing with the issue of stocking spare parts. The Aviation Supply Office (ASO) is responsible for implementing the part support policy for the aviation community. It determines which and how many spare parts will be carried. Budgetary and shipboard space limitations dictate an upper bound on the parts provided. ASO works closely with the fleet in balancing the demand for spare parts with these limitations.

There are two basic questions ASO answers in determining what type of parts support will be provided to a system. First, what types of spare parts are needed to keep this system functional? The variety of parts carried to support a system determines the stock range. Second, how many of these spares should be carried? The quantity of a part carried to support a system determines the stock depth.

The Aviation Consolidated Allowance List (AVCAL) was developed by ASO to meet the demand in both range and depth for spare parts required by a ship or Marine Air Group. Determining the AVCAL is a complicated process involving projecting expected flight hours, and forecasting demand based on past experiences. Consumables (failed components that are discarded) are stocked to a quantity sufficient to satisfy 85% of all units requested in a 90-day period. The requests are based on a Poisson distribution. Repairables are stocked to a quantity sufficient to provide 90% protection

against being at least one unit short. The demand is based on the Poisson distribution with the Raw Pool Quantity (RPQ) being used as the average. The RPQ is the number of items expected to be under repair at any given time. For a more detailed explanation of AVCAL allowance procedures see [Ref. 1: pp. 17-26].

The Shore Consolidated Allowance List (SHORCAL) is similar to the AVCAL but is used in computing the range and depth for spare parts for Marine Corps Air and Naval Air Stations. The main difference is, AVCAL is based on a 90 day cycle while SHORCAL is based on a 30 day cycle when allowances are computed.

Both of these systems are designed to meet most of the demand for parts. Being stocked to meet 100% of the demand would be cost prohibitive. A shortcoming of determining parts allowances using the ASO method is its lack of sensitivity to being out of stock. ASO looks at the probability of being out of stock not the expected number of units short. Being out of a part for one day carries the same weight as being out of that part for three days. From the viewpoint of aircraft readiness this difference is significant.

Another aspect of the problem is the lack of a standard by which to measure an aircraft's readiness. Several programs in use include the Unit Status and Identity Report (UNITREP), Full Mission Capable percents (FMC) and Subsystem Capability and Impact Reporting (SCIR). The impact of a part not being available on any of these measures has been studied by various organizations in the last few years. RAND corporation developed a large scale model which looks at wartime resupply called The Dyna-METRIC Readiness Assessment Model. The Center for Naval Analysis has two models they developed called MIME and the Aviation Logistics Model. All of these models are used primarily as research tools and are not used by ASO in determining a stocking policy.

B. OBJECTIVES AND SCOPE

The objectives of this thesis are:

- Determine the major contributors towards aircraft readiness within the scope of this thesis.
- Develop a model that predicts the impact of aircraft readiness within the scope of this thesis.
- Perform a sensitivity analysis on the major contributors to determine the weight each has on aircraft readiness.

The objectives listed above are very broad and complex in nature. There are many factors that determine aircraft readiness. Therefore, in order to do an in depth study within the constraints of this thesis, the scope was very specific. Supply stocking levels and IMA repair capability were the only factors considered in this study of aircraft readiness. The reader is cautioned not to generalize results beyond the scope in which these objectives were looked at.

In order to solve a problem which spans across organizational level maintenance, supply and intermediate level maintenance one component at one location was selected. The CN1561/ASN130 inertial navigation system (INS) for the F/A-18 was selected as the component to be studied for several reasons. It has been identified to be a top readiness degrader for the F/A-18 and it is supported by a dedicated test bench. The TS-3846/ASM-608 Inertial Measurement Unit Test Set (IMUTS) at the Intermediate Maintenance Activity (IMA) was designed to repair only the INS. This had the advantages of no competition by other systems needing repair. Strike Fighter Squadron 125 (VFA-125) at Naval Air Station Lemoore was selected since it is the largest squadron and largest demander of ASN130s at Lemoore. This is due to VFA-125's responsibility for training all west coast Navy and Marine Corps F/A-18 pilots before they report to their operational squadrons.

In meeting the thesis objectives stated earlier all of the analysis were done on data based on the ASN130. Each system on an aircraft has its own unique characteristics in parts support and maintenance support. This will become more evident later as the characteristics of this system are discussed. For this reason conclusions reached concerning this system may not apply to other dissimilar systems.

C. PREVIEW

Chapter II will discuss VFA-125's maintenance practices with regards to the ASN130, the supply policies in meeting the demand and the IMA's maintenance practices in repairing the ASN130. A method for quantifying aircraft readiness will be discussed. This will be used as a measure of effectiveness (MOE) by which the impact of being out of stock can be quantified.

Chapter III will cover the data base for this thesis. Where the data originated, how it was collected and some of its inconsistencies will be discussed. This includes data from VFA-125, supply, the IMA, the Naval Aviation Logistics Data Analysis (NALDA) system and the Analytical Maintenance Program Analysis Support System (AMPAS). Costing data obtained for the parts from the ASO will also be discussed.

Chapter IV will address the first two objectives of this thesis and present the model formulation. The assumptions made will be clarified as well as their impact on the model. A computer simulation will be developed to model the reality implied by the data.

Chapter V will address the last thesis objective. A sensitivity analysis of the computer simulation will explore the impact of varying the variables used in the model. The cost of the feasible options discovered in the sensitivity analysis will also be discussed.

Chapter VI presents a recapitulation of the thesis research as well as the conclusions suggested by the simulation model. Finally, recommendations will be made based on the conclusions on how aircraft readiness can be improved within the scope covered by this thesis.

II. PERSPECTIVE

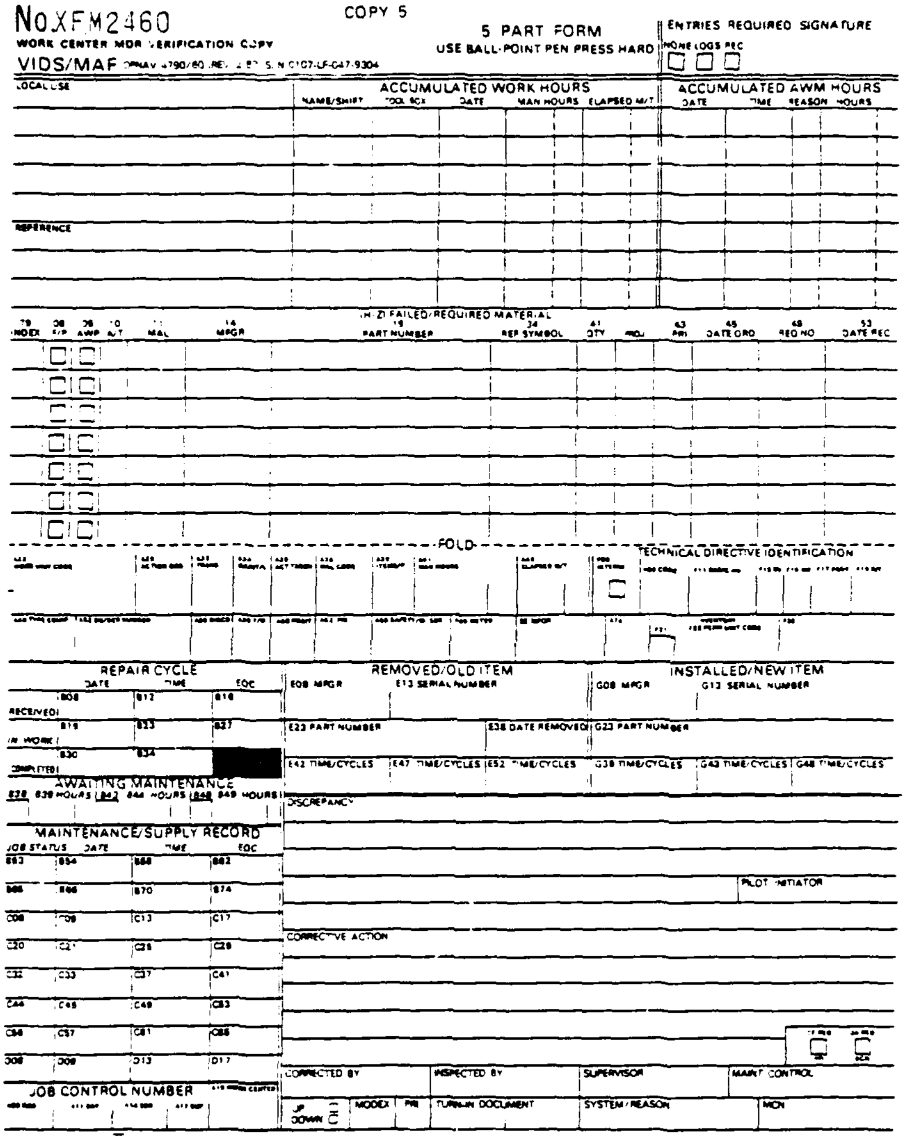
A. MAINTENANCE ORGANIZATION

There is no widely accepted definition of aircraft readiness in the Navy. A squadron's readiness is not necessarily equal to the sum of the readiness of each aircraft. A fully ready squadron may not need all of its aircraft to conduct one or two missions. However, this thesis will focus on the readiness of each aircraft. The ASN130 Inertial Navigation Unit simplifies the study of an aircraft's readiness. If the ASN130 is functioning the aircraft is ready assuming it is not down because of some other defective component. This means that the aircraft is 100% ready, Full Mission Capable (FMC), if the ASN130 is functioning and 0% ready, Not Mission Capable (NMC) if the ASN130 is not functioning. Other systems make this analogy more difficult because, even if such a system is down, the aircraft may be able to complete some of its missions. This aircraft would be Partial Mission Capable (PMC). OPNAVINST 5442.4K [Ref. 2] contains a Mission Essential Subsystems Matrix which determines mission capability for each system.

A malfunctioning ASN130 is most likely to be discovered by the pilot during preflight checks. If the flight is important the squadron may decide to remove a working ASN130 from another aircraft and install it on the aircraft getting ready to launch. It takes about five minutes to remove an ASN130 and it can be installed in an aircraft with power on and the pilot sitting in the cockpit. This procedure is known as cannibalization. It is a frequently used practice which allows expeditious access to a part which would otherwise take much longer to get through the supply system. The main disadvantage of cannibalization is that it takes twice as many maintenance actions to accomplish the same job.

Navy policy is that all maintenance conducted on aircraft will be documented. In the case of cannibalization, the maintenance technician will remove the defective part and write up a discrepancy on a Visual Information Display System / Maintenance Action Form (VIDS MAF). A copy of this form is shown as Figure 1.

If the flight is not a high priority flight or the decision is made not to cannibalize another aircraft the pilot shuts down his aircraft and returns to the squadron's maintenance control and writes up a discrepancy on a VIDS MAF. The VIDS MAF serves as a connecting link between the defective component and all maintenance and logistics



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VIDS/MAF

5 PART FORM

USE BALL-POINT PEN PRESS HARD

ENTRIES REQUIRED SIGNATURE

LOCAL USE

ACCUMULATED WORK HOURS

NAME/SHIFT DATE MAN HOURS ELAPSED M/T

ACCUMULATED AWM HOURS

DATE TIME REASON HOURS

REFERENCE

FAILED/REQUIRED MATERIAL

PART NUMBER REF SYMBOL QTY DATE ORD REQ NO DATE REC

FOLD

TECHNICAL DIRECTIVE IDENTIFICATION

REPAIR CYCLE

DATE TIME EOC

RECEIVED

IN WORK

COMPLETED

AWAITING MAINTENANCE

MAINTENANCE/SUPPLY RECORD

JOB STATUS DATE TIME EOC

JOB CONTROL NUMBER

REMOVED/OLD ITEM

E13 SERIAL NUMBER

E23 PART NUMBER

E38 DATE REMOVED

E42 TIME/CYCLES E47 TIME/CYCLES E52 TIME/CYCLES

INSTALLED/NEW ITEM

G13 SERIAL NUMBER

G23 PART NUMBER

G38 TIME/CYCLES G43 TIME/CYCLES G48 TIME/CYCLES

DISCREPANCY

PILOT INITIATOR

CORRECTIVE ACTION

CORRECTED BY INSPECTED BY SUPERVISOR MAINT CONTROL

UP DOWN MODEX PRI TURN-IN DOCUMENT SYSTEM/REASON MCN

Figure 1. Sample VIDS/MAF Used in Documenting ASN130 Discrepancies

actions that occur to that component until it is fixed or determined to be Beyond the Capability of Maintenance (BCM).

Maintenance Control assigns a Job Control Number (JCN) to the VIDS MAF and sends it to the proper repair shop. Each repair shop is capable of conducting maintenance on specific Work Unit Codes (WUC). The WUC is used to relate maintenance actions to a specific system. The WUC for the ASN130 is 73M1800.

The squadron maintenance technician takes the defective component to a test bench to verify that the ASN130 is not functioning properly. This check takes approximately 15 minutes. Once the malfunction has been verified a request is sent to supply for a functioning ASN130 and the defective ASN130, now called a carcass, is turned in to the supply system. The complexity of the ASN130 prevents any repairs from being made by the squadron's mechanics. Most other systems allow many of the repairs to occur at the squadron's level of maintenance (O level maintenance).

The ASN130 is a component with a high failure rate and a high interest level because of its criticality. For this reason, the air station supply department has a rotatable pool which tracks items like this. The rotatable pool is a backup inventory of parts the air station keeps in a warehouse. The Petty Officer who runs the rotatable pool receives a request over teletype within minutes of the time the squadron sends the request. If he has the part in stock he will send a truck to the squadron to deliver a functioning ASN130 and pick up the squadron's carcass. The Uniform Military Movement Issue Priority System (UMMIPS) time standard is to fill all requests within one hour if the part is in stock. If after one hour the squadron has not received a new ASN130 the date and time are noted by the squadron's work center responsible for replacing the ASN130. When supply finally delivers an ASN130 the date and time are again noted by the same work center. The difference in these dates and times is recorded as Subsystem Capability Impact Reporting (SCIR) supply hours. SCIR supply hours are hours during which the aircraft is not FMC due to waiting on parts from supply. SCIR hours can also accumulate if the aircraft is not FMC due to maintenance personnel not being able to fix the discrepancy, provided the part is available. These are SCIR maintenance hours. SCIR hours are recorded for each aircraft for each month. These hours are also recorded for each Work Unit Code.

Sometimes the carcass is not turned in to supply the same day the failure occurs. A failure may occur during the weekend when the rotatable pool is closed. A failure may

occur when the aircraft is on a training exercise away from Lemoore. There are numerous other reasons to explain this occurrence that will not be discussed here.

Once supply has custody of the carcass they immediately turn it in to the IMA for repair. At Lemoore the rotatable pool is located in the same building as the work center which repairs the ASN130. Work center 62F is available to repair the ASN130 seven days a week.

At the work center the ASN130 is first connected to one of the two IMUTS test benches. A four-hour diagnostic check isolates one of 13 subcomponents as defective. These subcomponents are called SRAs (System Repairable Assemblies). There are two basic types of repairs that are usually needed. If the ASN130 is operating improperly due to an incorrect signal a simple adjustment may correct the discrepancy. This is the case about 65% of the time. If the ASN130 is operating improperly due to a malfunctioning SRA a new SRA is ordered from supply to replace the defective one. In either case, following repair the ASN130 is put back on the bench and retested to ensure proper operation before it is returned to supply in a Ready For Issue (RFI) status.

Approximately 3% of the time work center 62F will be unable to repair the ASN130. In this case the entire unit (called a WRA for Weapons Repairable Assembly) will be sent to another maintenance facility with greater capability. This is the depot level of repair. The WRA is overhauled completely at the depot. As a consequence, the time and cost for this level of repair is much more than that of the IMA.

If the ASN130 requires a part (SRA) during repair at the 62F workcenter a request is made to the supply department for that part. Nothing is done to the ASN130 until the SRA is received by the work center. This time is documented as time awaiting parts (AWP) by work center 62F. The processing of the defective SRA follows one of two courses of action. It may be sent to another work center to be repaired. This requires special equipment and technicians capable of isolating and repairing circuits on the SRA. Benches such as the AN USM-484 Hybrid Test Set (HTS) or the AN USM-470 Avionic Test System (ATS) are designed to meet this requirement. Alternatively, a defective SRA may be automatically BCM'd to the depot if the IMA does not have the capability to repair it. This is the case for the Platform Assembly, which is the SRA which fails with the greatest frequency. To reduce the AWP time the supply department carries more of the Platform Assemblies in stock.

There are several other factors that may affect the repair capability of an IMA that will not be important in the analysis in this thesis but need addressing. An IMA provides

maintenance support for an airwing if deployed aboard an aircraft carrier or for a geographic region if established at a naval air station. This support can often impose such burdens on an IMA that it may be manpower limited or test bench limited. Manpower limitations were not a problem during this thesis effort since two of the squdrons had been deployed reducing the number of ASN130s that failed. The test bench was also not a problem. The IMUTS is dedicated solely to the repair of the INS. Other test benches such as the HTS, ATS and the AN USM-247 Versatile Avionics Shop Tester (VAST) can repair many components off of many aircraft. This multipurpose design reduces the number of test benches an air wing would require to support it. This is important on aircraft carriers where space is a premium. But this design feature comes with a price. A test bench can test only one or two components at a time. Each test can take up to ten hours. Additionally, the bench must be physically reconfigured to properly interface with each of a wide range of electronic components. This interface must then be tested, a process that can take another eight hours. For this reason, after a bench is configured for a specific component a large batch should be tested. Fortunately, this factor did not have to be considered for the ASN130.

B. MEASURE OF EFFECTIVENESS

The objective of this thesis is to find supply and IMA related factors which have an impact on aircraft readiness. A measure of effectiveness (MOE) had to be carefully chosen. The MOE chosen has to reflect a degradation in an aircraft's readiness as well as relate this degradation to actions by the supply department and the IMA. SCIR supply hours was chosen as the MOE. As discussed earlier it is the number of hours the aircraft cannot conduct its mission because supply does not have the part on hand when there is a demand for it. For the remainder of this thesis SCIR supply hours will be referred to as merely SCIR hours even though actual SCIR hours include SCIR maintenance hours as well.

There are several parameters which provide inputs into SCIR hours. First there is the demand for spare parts. This demand is a consequence of random failures of some system on the aircraft. Another obvious parameter is the level of stock maintained by the supply department for each part. Higher stock levels should cause lower SCIR hours, everything else remaining constant. A not so obvious parameter is the Turnaround Time (TAT) of the IMA. The TAT is the time between discovery of a component's failure and its return to an RFI status or the conclusion that it should be BCM'd. The TAT is the sum of several other times. These are:

1. Processing Time (PRO), the time between the date the JCN was assigned and the component was turned in to the Aeronautical Material Screening Unit (AMSU). The AMSU is responsible for routing the failed component to the correct work center for repair.
2. Scheduling Time (SCH), the time between receipt of the component by AMSU and induction into a work center for repair.
3. Repair Time (REP), the time between induction into a work center of a component and completion of a RFI/BCM action, less any awaiting parts time.
4. Awaiting Parts Time (AWP), the time a component can not be worked on while waiting for parts. This occurs between its induction into the work center and completion of a RFI/BCM action.

See [Ref. 3: p. 7-82] for greater detail.

PRO and SCH times are a function of management and policy. REP time is a function of manpower, bench availability and the exact nature of the failure itself. As stated earlier, manpower will not be a factor in the analysis of the ASN130. AWP time is a function of stock levels of the SRAs and other work center's capabilities to repair those SRAs.

The availability of the work bench was determined by dividing the time the test bench was up (Up_t) by the total time the test bench was available ($Up_t + Down_t$) to conduct repairs of the ASN130. The following formula was used in computing the test bench availability.

$$A_o = \frac{Up_t}{Up_t + Down_t} \tag{2.1}$$

A standard was needed for bench availability to measure its effects on repair time. If the test bench is significantly effecting repair time then it is a contributing factor to TAT and possibly aircraft readiness. Later in this thesis, bench A_o will be examined for its effect on REP time.

III. DATA BASE

A. SQUADRON DATA

Data was collected on VFA-125 from two different sources. First, existing Maintenance Data Reports (MDR) were collected monthly from the squadron. The format for MDR reports can be found in [Ref. 3]. The Maintenance Action by System and Component Report (MDR-6) was used to collect data on WUC 73M1800 (the ASN130). This report gave information on the failures of the ASN130. Specific information of interest included the aircraft tail number (buno) the ASN130 was removed from, the JCN, the repair date and the Action Taken (AT) code. The JCN is specific to each discrepancy. The first three characters identify the activity from which the discrepancy originated. The next three numbers indicate the Julian date the discrepancy was first noted. This is assumed to be the removal date of the failed component. Usually maintenance technicians are able to start work on a JCN within hours of its origin. The last three numbers of the JCN are to ensure discrepancies from the same activity on the same day are uniquely identified.

Two different SCIR reports were studied next. The Monthly Equipment Mission Capability Summary Report (SCIR-5-1) provided a breakdown of SCIR hours by WUC. NMC hours due to supply for WUC 73M1800 were obtained from this report. The Monthly Mission and Maintenance Data Detail by Bureau Serial Report (SCIR-5-3) provided the NMC SCIR supply hours for each aircraft, AT code and JCN. The precise origin of SCIR hours could be obtained this way. This was important for the model development.

The reports discussed above were all produced at Lemoore from a computer database which originated with the VIDS/MAF. Copies of the VIDS/MAF are sent to the Navy Management Systems Support Office (NAVMASSO). NAVMASSO enters the VIDS/MAF information in their computer database. The Naval Aviation Logistic Data Analysis (NALDA) and the Analytical Maintenance Support System (AMPAS) are two computerized systems designed to process the NAVMASSO data and provide this information to the fleet via remote terminals. Personnel assigned to the Commander, Naval Air Force, Pacific Fleet have access to these terminals, and provided a computer listing of all maintenance actions for WUC 73M1800 at NAS Lemoore for an 18-month

period. The NALDA system provided information similar to the MDR-6. The AMPAS system provided information similar to SCIR-5-1.

The squadrons MDR and SCIR reports were only available from March to November 1987. The NALDA and AMPAS data was available from June 1986 to November 1987. Because of the uncertainty of deployment schedules, data prior to March 1987 was not used. The daily failures of ASN130s were constructed from the data covering March to October 1987. During these 245 days, 120 failures of the ASN130 occurred at VFA-125. Appendix A lists the daily demand for ASN130s from VFA-125.

Five months of data were analyzed to determine the precise origin of SCIR hours. Most of the SCIR hours are associated with maintenance actions involving cannibalizations. This was determined from the SCIR-5-3 report which related SCIR hours to buno numbers and AT codes (such as cannibalization). This is not a surprising result. Since cannibalization of parts normally occurs on aircraft that are down for another reason it makes sense to use parts from those aircraft. This reduces the impact of not having the part in stock. The fact still remains that lack of that part at that time still reduces the capability of that aircraft.

Table 1 shows a breakdown of the AT codes for each of the ASN130 demands for the five months described above. An AT code of R meant the ASN130 was removed and replaced from the aircraft. An AT code of T meant the ASN130 was cannibalized from one aircraft and put on another aircraft.

Table 1. ORIGIN OF SCIR SUPPLY HOURS

	Number	Percent
AT code of T resulting in SCIR sup hrs	19	90.5
AT code of R resulting in SCIR sup hrs	2	9.5
AT code of T not resulting in SCIR sup hrs	7	9.6
AT code of R not resulting in SCIR sup hrs	66	90.4

B. IMA DATA

Repair data was obtained about the IMA at Lemoore from the Repair Cycle Data Report (MDR-9). Information used from this report included the JCN, Action Taken code, Processing time, Scheduling time, Repair time, Awaiting Parts time, Total Turnaround Time and Completion Date. Action Taken codes 1 through 9 at the IMA were

used when the ASN130 was BCM'd. There are nine different reasons for an IMA to BCM a component.

All 120 ASN130s that failed at VFA-125 from March to October were sent to the IMA at Lemoore to be repaired. The TAT for 114 of the ASN130s appeared in the MDR-9 as being repaired by work center 62F. The other six ASN130s may have been repaired by another work center. The TAT for those six ASN130s could not be determined. The TAT was essential in reconstructing the day ASN130s were returned to the rotatable pool where they were then available for reissue. The average TAT for ASN130s for the month was used in estimating the six unknown TATs. Appendix A lists the TAT for each failed ASN130. When estimated, the TAT appears in parenthesis.

The TATs for the 120 maintenance actions were divided into their various components and summarized in Table 2. Total Days lists the total number of days associated with each category. Number Process is the number of ASN130s that were processed through each category. Average days is the average turnaround time of each category. Percent of TAT is the average percent of the total turnaround time contributed by each category. Many of the ASN130s spent more than one day in each category. Some of the ASN130s spent only a few hours in a category for which zero days were reported on the MDR-9.

When a sensitivity analysis is done later in this thesis on PRO, SCH and AWP time it will be important to know the maximum reduction feasible in each of those categories. There are a variety of reasons causing an ASN130 to spend more than one day in any category. Assuming that these reasons could be resolved and that the maximum amount of time an ASN130 would spend in any category is one day, the results listed under the column Min Days would have been observed. Min TAT is the TAT possible for each category if Total Days were reduced to Min Days. For example, AWP time might be reduced from Total Days down to Min Days (best case) by having more SRAs in stock. Table 2 shows that the most promising reductions in total TAT will occur by reducing PRO and AWP time. This information will be used later in the thesis.

A sensitivity analysis will not be done on REP time since the assumption was made that man hours are not a limiting factor in the repair process. For that reason a not applicable (N/A) will appear for repair time under some columns.

The technical representative for the IMUTS test bench provided a list of dates and times when either bench was down. At no time during the period of this analysis were both test benches down at the same time. Appendix B lists the A_o for the two IMUTS

Table 2. COMPOSITION OF TAT

	Total Days	Number Process	Average Days	Percent of TAT	Min Days	Min TAT
PRO time	194	114	1.7	38.8	79	3.4
SCH time	30	114	0.3	6.0	26	4.3
AWP time	128	36	3.6	25.6	36	3.6
REP time	148	114	1.3	29.6	N/A	N/A
Total	500	114	4.4	100.0	N/A	N/A

test benches. During May and September larger-than-average down times occurred due to a failure of a component on the test bench which took a week to receive the replacement part for.

Supply data was obtained from Lemoore's Supply Department and ASO. Component purchase price, BCM cost and pool allowance levels can be found in Appendix C. Daily stock levels for specific WUCs would have been helpful in the model validation but that information was not available. The estimated stock level that appears in Appendix A will be discussed in the next chapter.

IV. MODEL FORMULATION

A. INTRODUCTION

The squadron, IMA and supply system all have possible inputs that may effect SCIR hours. The demand rate for ASN130's is determined by the squadron. The demand rate could be a function of a wide variety of factors such as flight hours and sorties. A Masters Thesis by Steven Phillips concluded that there was a high correlation between flight hours and sorties on failure rates [Ref. 4].

Cannibalizations also seemed to be a likely candidate for impacting SCIR hours. Cannibalization, as discussed in Chapter 2, is the process of removing a part from a lower priority aircraft to use on a higher priority aircraft when a part is not readily available from supply. The first model used cannibalization actions as a variable. A high correlation between the number of cannibalizations and SCIR hours occurred. This was expected since 90.5% of all VIDS MAFs due to cannibalizations resulted in SCIR hours as shown in Table 1. A closer look at the problem indicated cannibalizations were not a cause of SCIR hours. The SCIR hours were caused by the supply repair system not being able to provide the part when demanded caused SCIR hours. This same lack of spare parts also causes cannibalizations. In order to reduce the impact of not having an ASN130 available from supply, maintenance would frequently remove an ASN130 from an aircraft which would not be flown in the near future to use on another aircraft. The number of SCIR hours due to the lack of an ASN130 would not change but the aircraft associated with those SCIR hours would be the lower priority aircraft. Since cannibalizations were not a causal factor of SCIR hours, the number of cannibalizations was not used as a variable in later models.

The IMA has several factors which may effect SCIR hours. The IMA has an influence over the TAT and the BCM rate of the ASN130. Although TAT is influenced by all of its subcomponents, it will be treated as a single variable. The sensitivity of TAT to the component times will be examined in the next chapter.

One of those subcomponents, repair time, may be influenced by the availability of the IMUTS test bench. The impact of IMUTS A_o on repair time is unknown however. IMUTS A_o was very high most of the time while the repair time varied. A plot of IMUTS A_o and repair time is shown in Figure 2. No trend is obvious from this figure so the availability of the IMUTS test bench will not be used in the model.

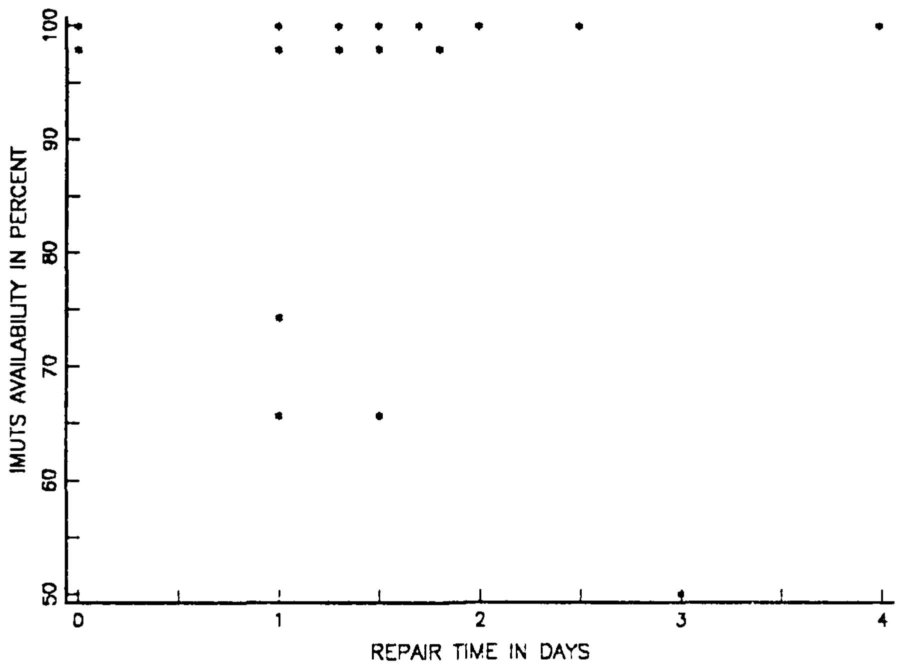

Figure 2. Repair Time vs IMUTS Availability for WUC 73M1800

The IMA has some control over the BCM rate. If an ASN130 is BCM'd, it is shipped off station. A replacement ASN130 is shipped back. On the average it takes an additional 30 days after the ASN130 was BCM'd to receive the replacement.

The stock level of ASN130s and the stock range and depth of SRAs needed to repair the ASN130s are maintained by the supply department. The stock level of the ASN130 has a direct relationship with the probability of a demand being filled by a part from stock. SRA stock levels influence the TAT by determining the AWP time.

B. PRELIMINARY MODELS

Several approaches were taken in the search for a model which accurately described what was occurring in reality. The model needed to be able to predict SCIR hours based

on the factors contributing to stock shortages. A model would also have to be flexible enough to show the impact of each of the variables on stock shortages.

A multivariable linear regression was one approach. The known SCIR hours were regressed against the demand rate, number of cannibalizations, the IMA's TAT and BCM rate. The results of this regression gave the weight each variable had in relating that variable linearly with SCIR hours.

The R-squared value, also known as the correlation coefficient, is a number between -1 and 1. A value of 1 implies that the variability of the X values can be explained 100% by the Y values. This is another way of saying there is a 1 to 1 correlation. A high correlation was observed with demand rate and number of cannibalizations. A low correlation was observed with the IMA's TAT and BCM rate. This model did not appear to relate the variables to SCIR hours with a high degree of accuracy. The R-squared value of 0.863 was computed using Grafstat in the IBM 3033 computer at the Naval Postgraduate School. Cannibalization carried the highest weight in this regression.

As explained at the beginning of this chapter SCIR hours were logged against cannibalized aircraft 90.5% of the time. With a linear regression model this would result in a high correlation between the number of cannibalizations and SCIR hours. However this correlation does not imply a cause and effect relationship. In this model it has already been stated that cannibalizations do not cause SCIR hours but rather the lack of spare parts cause SCIR hours and motivate cannibalizations.

The disadvantage of this approach was that it could only show the weights variables had but could not model how these variables actually contributed to SCIR hours. For example, SCIR hours were caused when there was not enough stock to meet demand. There are reasons why the stock level is not sufficient which this model did not answer. As a consequence, the regression model was abandoned.

A stochastic model was also considered. Queueing theory should be able to explain the periods where supply of ASN130s was insufficient to meet demand. Modeling one ASN130 in the system was not difficult. A Markov transition matrix could be easily calculated which gave the probabilities of being in all possible states. A state is a snapshot in time which shows were the ASN130 is located in the aircraft-supply-repair system. However, the purpose of this thesis is to model all of the aircraft and ASNs in a geographic location. The transition matrix becomes extemely large when all possible states that might occur are included. The identification of all the states would take a very long time. The queueing approach was not used for those reasons.

C. SCIR MODEL FORMULATION

The combination of uncertainty and the complex interdependencies among variables in the system combined with the need for finely defined time intervals were too complicated to handle with linear models or standard probabilistic models. This type of problem is best approached by a simulation. A simulation builds an experimental model of a system, then varies specific alternatives which are evaluated in reference to how well they fare in test runs of that model [Ref. 5: pp. 905-906].

This section will introduce the formulation of the computer simulation model. The next chapter will use the simulation model developed to predict an outcome. That outcome will be compared with the actual outcome in testing the simulation's validity.

Basically the simulation model will count the times when the demand for ASN130s exceeds what is available. SCIR time (in days) is the sum of all the daily shortages of ASN130s. The demands for ASN130s will be generated by the simulation from a known probability distribution. The supply of ASN130s is determined by the stock level in the warehouse plus the number of ASN130s repaired. The repair of ASN130s is generated by the simulation of a known probability distribution fitting the actual repair data.

SCIR time will result when the demand for ASN130s is greater than the number of ASN130s supply has in stock. The number of ASN130s that supply has on day i is equal to the quantity of ASN130s remaining in stock from the day before (i-1) plus the quantity of ASN130s the IMA returns to the pool on that day (i) first thing in the morning minus the demand for ASN130s on day i. If the number of demands exceeds the number of ASN130s in stock on a given day, then the SCIR hours for that day are assumed to be twenty-four for each demand which cannot be filled. Suppose that over a period of three days, demand exceeds supply by two ASN130s on day 1, supply exceeds demand on day 2 and demand exceeds supply by one ASN130 on day 3 then over that three day period there was a shortage of three ASN130s for twenty-four hours. In this model that is equivalent to being short one ASN130 for seventy-two hours. SCIR time (in days) is the sum of all the daily shortages of ASN130s. The following mathematical model describes this SCIR time.

$$SCIR = \sum_{i=1}^{n} Shortage_i \quad , \tag{4.1}$$

where

$Shortage_t = 0$ if $demand_t \le inventory_{t-1} + repair_t$,

$Shortage_t = (demand_t - inventory_{t-1} + repair_t)$ if $demand_t > inventory_{t-1} + repair_t$.

Demand, inventory and repair are in units of ASN130s. Daily shortage is in units of ASN130 days. SCIR is the sum of shortage over n days. It can also be viewed as the number of days that the supply department is short one ASN130.

D. ASSUMPTIONS

Demands for ASN130s, repair of ASN130s and the quantity of ASN130s in supply change continuously through time. However, the data used in this thesis only provided the quantity demanded and quantity repaired of ASN130s for each julian date. This means that there is no information on the time of day these failures or repairs occurred. Although a failure or repair can, in reality, occur at any time during the day in this model it is assumed that they occur at the same time of day.

The simulation model is influenced by several variables. If these variables fit known distributions the simulation process will be simplified. Known distributions have easily calculated means and variances. The density function can be easily described mathematically and programmed.

The demand is the number of ASN130s desired by the squadron each day to replace the ones that failed. Daily demand is equal to the number of ASN130s that failed on that day. This is an integer variable with a discrete probability distribution. The TAT is also an integer variable which has a discrete probability distribution. When an ASN130 is inducted into the IMA it is either repaired or BCM'd. The variable BCM also has a discrete distribution.

The distributions assumed for use in this model are:

1. Daily demand of the ASN130 fits a geometric distribution.
2. TAT of the ASN130 for the IMA fits a geometric distribution.
3. BCM fits a bernoulli distribution with the probability of 0.025 that an ASN130 will be BCM'd after induction into the IMA.

Their validity will be discussed in the next section. Other assumptions used in the simulation model are:

1. After an ASN130 is BCM'd its replacement is returned from the depot and added to the pool 30 days later.
2. Failures of ASN130s occur at the same time if more than one occurs on any day.
3. Repairs of ASN130s occur at the same time if more than one occurs on any day.

4. All repairs for that day are put in stock before any demand for them occurs.
5. The number of ASN130s in VFA-125's part of the rotatable pool is three.
6. Repairs of ASN130s from other commands have no impact on the IMA's TAT.
7. The IMUTS has no effect on repair time.
8. The IMA did not have a shortage of manpower required to repair the ASN130.

E. VALIDATION

All statistics were computed by the statistical computer package Grafstat on the IBM 3033 of the Naval Postgraduate School. Appendix A lists the failures (demands) that occurred on a daily basis. There were 120 failures that occurred in the 245 days between March and October 1987 at VFA-125.

The first hypothesis concerning distributions was that demand for ASN130s fits a geometric distribution. A Chi-Square goodness of fit test was conducted. The hypothesis would be rejected if the Chi-Square test statistic exceeds 5.99. This is based on a 95% confidence interval and two degrees of freedom. The test statistic for the data is 1.580, clearly less than 5.99. Therefore the hypothesis is accepted.

Table 3 provides the Chi-Square summary statistics. The mean and standard deviation of the data as well as the fitted distribution are listed. The Chi-Square value is computed by summing the test statistics for each interval. The Chi-Square Goodness of Fit Table lists the number of observed data values, the expected number of values and the test statistic for each range of days. For example, there was zero demand for ASN130s 159 out of 245 days. An exact fit of the geometric disribution would have zero demand 164.45 out of 245 days. This difference contributes 0.181 to the Chi-square test statistic.

The actual frequency of the number of failures was plotted over the geometric distribution shown in Figure 3. The largest number of failures observed on any day was four.

There are two forms of the geometric distribution. They differ only in their range. One form has a range from zero to infinity as in the case of failure times. The other has a range from one to infinity as in the case of TAT (there were no TATs less than one day). Since the statistical package used could only evaluate geometric distributions with ranges from zero to infinity a transformation, subtracting one day from each TAT value, had to be performed on the TAT data to get it in the appropriate form for the hypothesis test. There were 120 TATs in the data set, six of which were estimated. This was discussed in the preceding chapter. The statistical analysis was done on the 114 TATs which

Table 3. CHI-SQUARE GOODNESS OF FIT TEST OF THE GEOMETRIC DISTRIBUTION FOR DAILY FAILURES OF THE ASN130

DATA FIT FAILURES (number of failures per day)

	DATA	FITTED	GOODNESS OF FIT	
MEAN :	0.4894	0.4898		
STD DEV :	0.7925	0.8542	CHI-SQUARE :	1.580
			DEG FREED:	2

CHI-SQUARE GOODNESS OF FIT TABLE

LOWER	UPPER	OBSERVED	EXPECTED	TEST STATISTIC
-INF.	0.5	159	164.45	0.181
0.5	1.5	62	54.07	1.164
1.5	2.5	16	17.77	0.177
2.5	+INF.	8	8.71	0.057
TOTAL		245	245	1.580

had known values. To validate the second assumption the following hypothesis was formulated; that the adjusted TAT is a random variable from a geometric distribution. The hypothesis would be rejected if the Chi-Square statistic is greater than 18.31. This is based on a 95% confidence interval and 10 degrees of freedom. The computed Chi-Square statistic of 4.5671 is less than 18.31 so the hypothesis is accepted. Table 4 presents the results of the goodness of fit test. The transformed data TAT - 1 is shown plotted against the fitted geometric distribution as shown in Figure 4. The largest TAT - 1 value observed was 26 days.

Of the 120 units that were repaired, three of them were BCM'd. Therefore the probability of a unit being BCM'd was assumed to be 0.02521. A Bernoulli distribution is appropriate for a random variable which can take on only two possible values. An ASN130 is either repaired or BCM'd and thus can be considered to be a Bernoulli random variable.

On the average, 30 days after an ASN130 was BCM'd its replacement arrived. This is assumed to be constant due to the lack of data available to determine what type of distribution the replacement time would have fit.

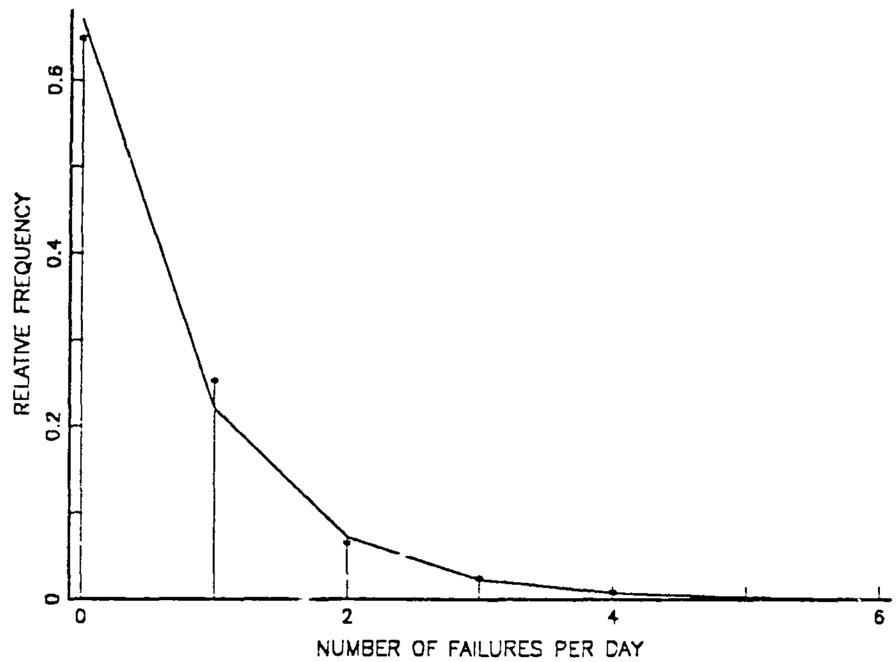

Figure 3. Comparison of the Fitted Geometric Distribution With the Data for the Daily Number of Failures of the ASN130; N = 245

It is estimated that VFA-125's share of the ASN130s in the rotatable pool is three. The actual stock allowance for the entire air station is 11 ASN130s. This is shared among all of the squadrons according to Navy policy for AVCAL covering several squadrons. No private pool truely exists.

To test the assumption that VFA-125's baseline stock level was three actual demands, TATs, and BCMs were used. The last column in Appendix A lists the inventory of ASN130s based on this assumption. Starting on February 28, 1987, with an inventory level of zero, three ASN130s were added to inventory during the next three days when they came out of repair. For every ASN130 short for a day, one day (24 hours) of SCIR time accumulated for that month. This was done every day from March 1 to to October

Table 4. CHI-SQUARE GOODNESS OF FIT TEST OF THE GEOMETRIC DISTRIBUTION FOR TAT - 1 DAYS OF THE ASN130

DATA FITTED TAT - 1 (Turnaround Time - 1)

	SAMPLE	FITTED	GOODNESS OF FIT	
MEAN :	3.386	3.386		
STD DEV :	4.134	3.854	CHI-SQUARE :	5.410
			DEG FREED:	10

CHI-SQUARE GOODNESS OF FIT TABLE

LOWER	UPPER	OBSERVED	EXPECTED	TEST STATISTIC
-INF.	0.5	23	25.992	0.348
0.5	1.5	16	20.066	0.824
1.5	2.5	15	15.491	0.016
2.5	3.5	11	11.959	0.077
3.5	4.5	13	9.232	1.538
4.5	5.5	9	7.127	0.492
5.5	6.5	5	5.502	0.046
6.5	7.5	3	4.248	0.367
7.5	8.5	2	3.279	0.499
8.5	10.5	6	4.486	0.511
10.5	13.5	2	3.573	0.692
13.5	+INF.	3	3.045	0.000
TOTAL		114	114	5.410

31. The predicted SCIR time (in hours) is listed along with the actual SCIR time in Table 5.

Over eight months 2124 hours of SCIR time were recorded. Using the assumption that the starting inventory of ASN130s was three, 2112 hours of SCIR time was predicted by the model. The model predictions worsened as starting inventory levels deviated from three ASN130s. If the starting inventory was four ASN130s the model would have predicted 1296 SCIR hours. If the starting inventory were two ASN130s the model would have predicted 4848 SCIR hours.

A plot was made of the predicted SCIR hours against the actual SCIR hours to further test the validity of assuming VFA130's initial stock level was three. A plot of the predicted SCIR hours and the actual SCIR hours would lie along a straight line having a slope of one and passing through the origin if the assumption were completely valid.

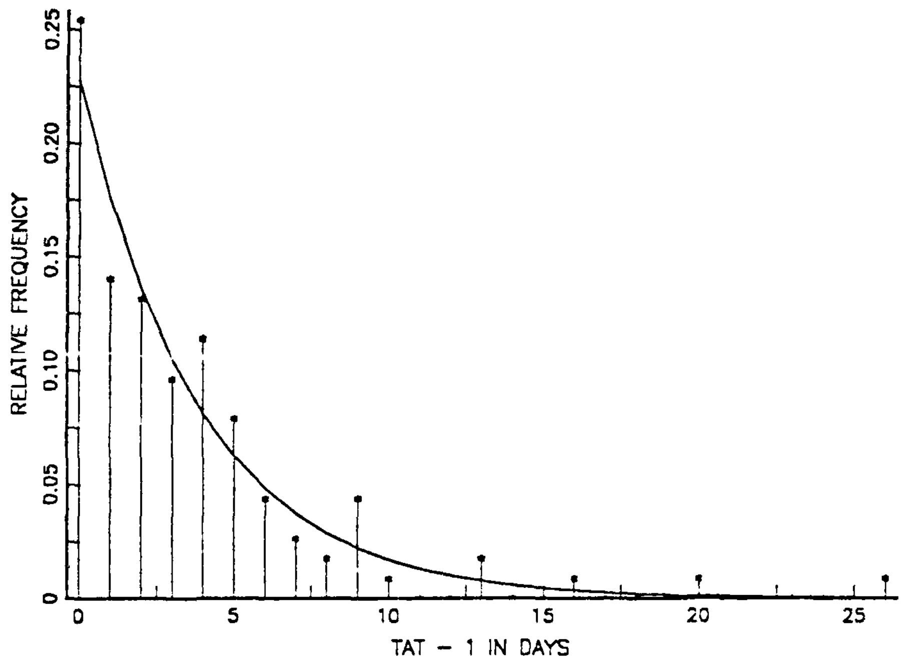

Figure 4. Comparison of the Fitted Geometric Distribution with the Data for the TAT - 1 Days of the ASN130; N = 114

This plot did not form a perfect fit so a least squares straight line was used. The statistics for fit of the model and the data are summarized in Table 6.

A plot of the predicted SCIR hours and the data SCIR hours with the least squares line is shown in Figure 5. The graph shows the data SCIR hours plotted against the predicted SCIR hours have a linear relationship. The coefficients portion of the table show a Y intercept occurs at 3.206 and the slope of the fitted line is equal to 0.994. The R-squared value of .9734 indicates a high correlation between the predicted SCIR and the actual SCIR hours.

Table 5. COMPARISON OF PREDICTED SCIR TO ACTUAL SCIR HOURS

Month	Predicted SCIR	Actual SCIR	Month	Predicted SCIR	Actual SCIR
March	576	583.1	July	168	171.5
April	408	449.8	August	384	324.5
May	264	257.4	September	48	43.7
June	168	194.3	October	96	99.7

F. COMPUTER SIMULATION

A computer simulation was written in Turbo Basic version 1.0 as the model and run on an IBM XT compatable. This was done in order to test the parameters of the model and their impact on SCIR hours.

The random number generator used in Basic generates a uniform random number between 0 and 1. The seed to start the random number generator was input from the computer's internal timer. Each random variable value that was used in the simulation was generated from a different uniform random number from this generator. Using transformations found in Ross, [Ref. 6: p. 455] the uniform random variables were converted to the appropriate geometric random variables.

The number of daily failures of ASN130s was modeled as a geometric random variable with parameter $p = 0.4894$ (p is the probability of at least one failure on any day). Using a geometric distribution to model ASN130 failures had one shortfall. Observations of the real data revealed that no more than four ASN130s failed on any given day. Since the geometric distribution could theoretically generate more than four failures on any day a transformation had to be made to simulate the actual failure data. If the computer generated four failures on any given day four failures and demands were placed on the supply system. If the computer generated five failures on any given day this was reduced to three. If the computer generated more than five failures on any given day that number was reduced to four. The transformed failure data from the simulation was almost identical to the Chi-Squared statistics of the original data. This redistribution only occurred 3% of the time.

Why were no more than four failures observed in the data on any given day? The specific reason is not known but there may be other mechanisms operating that put a

Table 6. STATISTICS FOR THE LEAST SQUARES FIT OF THE LINE RELATING PREDICTED AND ACTUAL SCIR HOURS

COEFFICIENTS

8 OBSERVATIONS R-SQUARED = 0.9734
2 VARIABLES

COEF	ESTIMATE	SIG LEVEL	0.95 CONFIDENCE LIMITS LOWER	UPPER
INTERCEPT	3.206	8.836E-1	-48.18	54.59
MODEL	0.994	5.940E-6	0.83	1.16

cap on the number of failures on a given day. For example, if maintenance control notices a high failure rate of ASN130s on any day they might change the order of business to respond to this or it may simply be unique to this sample of 245 days.

Because the simulation model was designed for conducting sensitivity analysis, the user was prompted for an average TAT which was converted to the parameter p (reciprocal of the average TAT) where p is the probability of a repair being finished on that day. To comply with assumption number four any repairs completed on a given day were added to the pool level from the previous day before filling any demands.

After an ASN130 went through a repair cycle (completed its TAT) it was BCM'd with probability 0.02521. If BCM'd its replacement was added to the pool 30 days later.

The simulation model also prompts the user for initial stock allowance. Initially a stock level of three was entered to correspond to assumption number five.

The simulation was allowed to run for 30 days before any data was collected. This was done to allow the model to reach equilibrium.

All of the random numbers that were generated as well as the daily failures, TATs, daily repairs and daily inventory levels were stored in arrays. This allowed for some of the parameters to be held constant while a sensitivity analysis was conducted on another parameter. For example, if variations in TAT were being examined the same demands and initial stock level were used for each TAT value. During each run in which the effect of increasing the stock level was being examined the same demands and TATs were used for each level. This was done for an increase in the pool of one, two and three ASN130s.

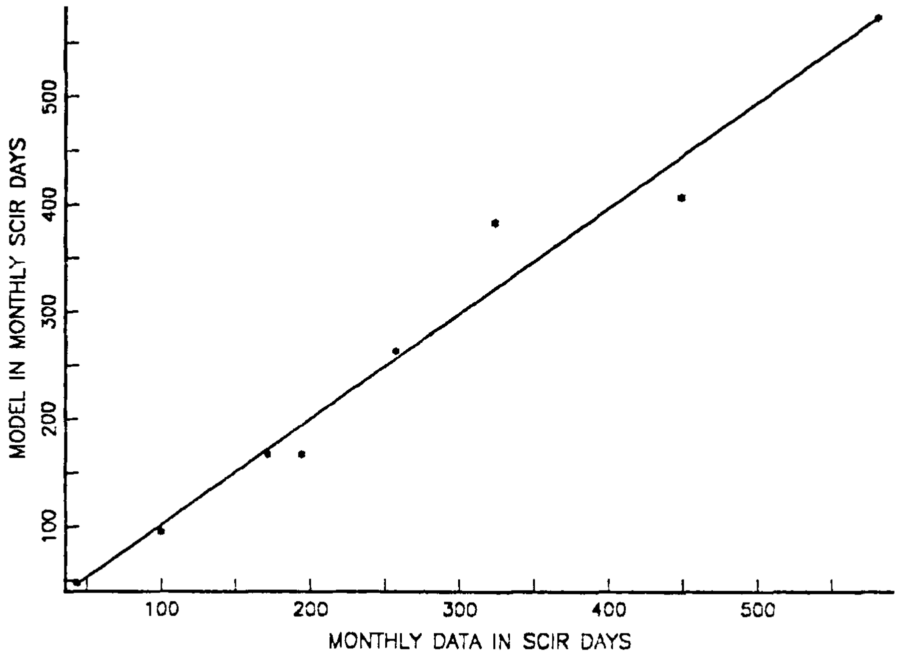

Figure 5. Comparison of Predicted SCIR Hours To Actual SCIR Hours

Appendix E has a sample computer output for the last 30 days of the simulation of run number five.

Statistics were computed for each month as well as for the entire 8-month run. The information was then either displayed on the screen or sent to the printer. The monthly summary included total number of failures, average TAT, SCIR days for the month, average TAT for the month and reduction in SCIR days as a result of having the starting pool level by one, two and three ASN130s. The eight-month run summary also included average TAT, total SCIR days, number of BCMs, and reduction in SCIR days due to one, two and three ASN130s in the starting pool. Over an eight month run the number of SCIR hours that occurred were large. SCIR hours were converted to SCIR days to reduce the scale. Twenty-four SCIR hours comprised one SCIR day.

This chapter discussed number of daily failures, TATs, BCM rate and stock level as inputs to the model for this thesis. Cannibalizations and the IMUTS bench A_o were not included as variables in the model. The simulation model was chosen as being the most useful after considering both a multiple regression and a probabilistic model. The next chapter will discuss the sensitivity analyses conducted using the simulation model.

V. SENSITIVITY ANALYSIS

A. RESULTS

Data was collected for 90 eight-month runs. Each run took about five seconds on a personal computer. The average TAT was varied from one to nine days in steps of 0.5 days. Data was collected at each of these TATs. Data was also collected for the average TAT of 4.35 days, the average for the actual data, to compare the simulation results with the real world data. Five simulation runs for each TAT were collected. An average value for each data point was computed and plotted. Appendix F has a listing of the output of each computer run. Figure 6 plots the average SCIR against its corresponding TAT value for four different starting levels of inventory. The curve marked normal in the legend was obtained from the computer simulations using a starting inventory of three ASN130s. The curve marked Up 1 in the legend was obtained from the computer simulations which used a starting inventory of four ASN130s. Curves marked Up 2 and Up 3 were obtained from computer simulations starting with five and six ASN130s, respectively.

The curves in Figure 6 show a nonlinear growth in SCIR time as TAT increases. This implies that a change in TAT from four to three days *will not produce the same* reduction in SCIR time as a change in TAT of six to five days. This could be important to a decision maker in deciding if a reduction in SCIR time were worth the cost associated with a reduction in TAT.

From March to October 1988, VFA-125 reported 2124 SCIR hours (88.5 SCIR days) for the ASN130. During that same time the average TAT of ASN130s at the IMA was 4.39 days. The computer simulation predicted an average SCIR time of 89.2 days over eight months with an average TAT of 4.35 days.

Reduction of SCIR hours can be achieved in two ways, reduction of TAT or increase initial stock level. They are not directly proportional approaches. The simulation predicts reduction of SCIR days from 90 to 40 by increasing starting inventory of ASN130s by one at 4.35 days average TAT. This same reduction in SCIR can be achieved by maintaining the initial stock level of three ASN130s and reducing the TAT from 4.35 days to about 3.1 days. The question facing the decision maker is whether it is cheaper to reduce TAT or increase the pool level. The decision maker is also faced with the question of how much reducing SCIR hours is worth.

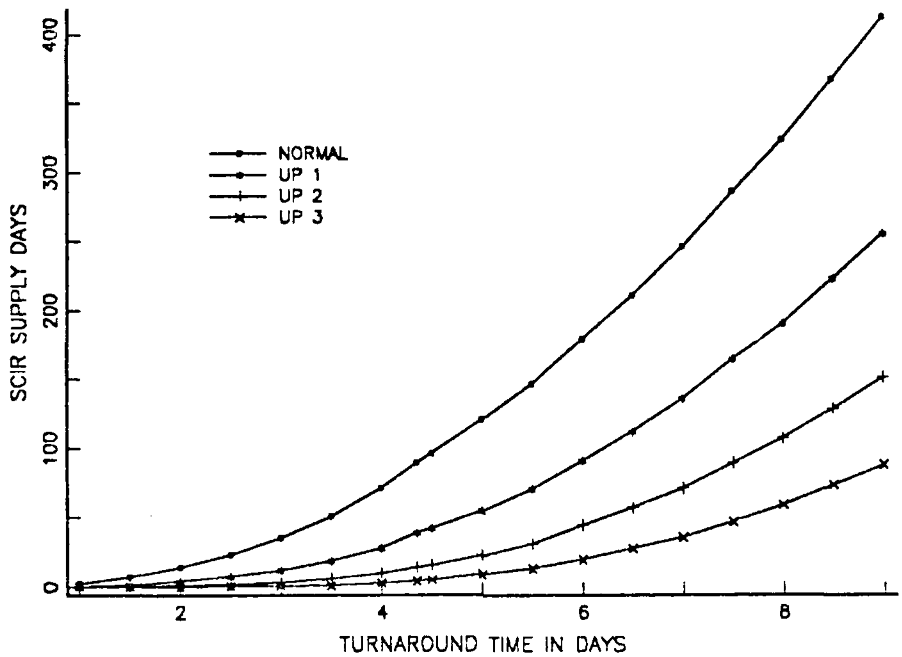

Figure 6. Simulated SCIR Days From 8-Month Simulations With Varying TAT and Stock Levels

B. COST ANALYSIS

The cost of spare parts must be addressed before any conclusions are reached, whether it is better to change the level of WRAs stocked or the value of TAT for the same reduction in SCIR supply hours. SCIR time can be reduced by increasing the initial stock level or by reducing TAT. By initially increasing the WRA by one at a cost of $118,000 the SCIR time would be reduced from 89.2 to 38.8 days. This was obtained from Figure 6 using an average TAT of 4.35 days. A similar reduction in SCIR time can be achieved by reducing the TAT without increasing the WRA allowance. A reduction in TAT from 4.35 to 3.6 would reduce SCIR time from 89.2 to 55 days. This reduction in TAT could be achieved by reducing AWP to one day. Table 2 on page 14 indicates

that of 114 ASN130s (WRAs) processed only 36 required parts (SRAs). Therefore increasing the WRAs stocked will have an affect on SCIR hours 100% of the time while increasing the SRAs will have an affect on SCIR hours 32% of the time. Additionally, using Table 2, if the AWP time could be reduced from its current average of 3.6 days to one day by having a large supply of SRAs the TAT of the WRA would be reduced from 4.4 to 3.6 days. In other words, the best TAT one could obtain by reducing AWP to its minimum is 3.6 days.

How much would it cost to reduce the average AWP time to one day is the only question remaining in this example. An accurate answer would require a complicated analysis by itself but a rough estimate will be attempted here. Eighty percent of the failures of the ASN130s are caused by the SRA called the platform assembly, part number 854100-5. This SRA cannot be repaired by the IMA and is automatically BCM'd. The cost to repair the platform assembly is \$14,400. To increase the pool level of that part by one unit would cost \$46,809. It would not be difficult to spend more than \$118,000 by increasing the allowance quantity of the platform assembly by three and also increasing the allowances of some of the other SRAs that fail frequently. Appendix C lists the cost information and allowance levels of the ASN130 and its SRAs.

Another possible way to reduce TAT would be by a reduction in processing time (PRO). That is the time between discovery of the failed component and its induction into AMSU. If PRO time were no longer than one day, the average TAT that was observed in the data could be reduced from 4.4 to 3.4 days. This could be done at a low cost by education or increasing the hours for parts turn in at the supply department. Often the maintenance technician is not aware of the relationship that exists between his turning in a broken part in an expeditious manner and the part's TAT. The exact cost to reduce PRO time is not known but it is likely to be less than the cost of reducing AWP time. The expected payoff should be the same.

VI. SUMMARY, CONCLUSIONS, RECOMMENDATIONS

A. SUMMARY

The following objectives were addressed.

- Determine the major contributors towards aircraft readiness within the scope of this thesis.
- Develop a model that predicts the impact of aircraft readiness within the scope of this thesis.
- Perform a sensitivity analysis on the major contributors to determine the weight each has on aircraft readiness.

Those objectives were addressed in the scope of looking at only the supply system and IMA's impact on aircraft readiness. SCIR supply hours were used as the MOE to define aircraft readiness since SCIR time was recorded for a specific component out of stock. This thesis looked at the ASN130, which is the Inertial Navigation System for the F/A-18 and the impact of the supply stock levels and the IMA TAT for the ASN130. The ASN130 was selected because of its high failure rate and NMC effect on the F/A-18 when it does fail.

A description of how the real world system worked was given in Chapter II. Chapter III discussed the origin of the data and how it was processed. Chapter IV presented the simulation model formulation. It was noted that SCIR supply hours accumulated any-time the demand for ASN130s exceeded the current pool inventory plus any ASN130s that might have been repaired in the IMA that day. The results of the sensitivity analyses on TAT and initial stock level of the rotatable pool were presented in Chapter V.

B. CONCLUSIONS

The following conclusions were reached in this thesis. These are ASN130 specific.

- The availability of the IMUTS test bench at the IMA had no effect on the TAT as long as at least one bench was available. No conclusions can be made on both test benches being down since this did not occur during March to October 1987 at NAS Lemoore
- SCIR supply hours were related to demand, TAT, the rotatable pool's stock level and BCM rate.
- To reduce SCIR supply hours, increasing the rotatable pool's stock level of ASN130s (WRA) appears more cost effective than achieving the same SCIR reduction by reducing AWP time by increasing the number of SRAs.
- A simulation model appears to be the best approach for this type of analysis.

- This model can be used for other WUCs, however the factors affecting SCIR time may vary. For example, the test bench nonavailability may increase repair time significantly.

C. RECOMMENDATIONS

The following recommendations are made as a result of the analyses in this thesis.

- A model based on demands, such as the one developed in this thesis, should be considered by ASO and NAVAIR to test spares policies and their impact on aircraft readiness. A model of this type would also be helpful in minimizing costs of spares while meeting some acceptable upper bound on SCIR supply hours. The current AVCAL model is designed to only measure the probability a part will be in stock when needed.
- The aviation community should develop a program of education on what factors are influencing shortages of spare parts. Some of these factors include processing time (the time between failure of the component and turning it in to the supply department) and AWP time. This would allow maintenance personnel to understand the impact they have on aircraft readiness.
- Reduction of Processing time is a low cost alternative which should improve aircraft readiness. Education of maintenance personnel and increasing the hours the rotatable pool is open could help make this possible.

Study should be continued to improve the knowledge of factors that affect SCIR time. Other areas to be considered would include studying the maintenance of the ASN130 on aircraft of squadrons deployed on an aircraft carrier for comparison to this study which considered a shore-based squadron. Other F/A-18 systems should be studied to identify the impact that other factors such as test bench availability could have on SCIR time. Finally, recording the daily stock level in the rotatable pool would be helpful in future studies to aid in validation of the simulation.

APPENDIX A. DAILY DEMAND AND REPAIR DATA

The following data is a reconstruction of the number of failures and repairs on each day from VFA-125 and the IMA's MDR reports. TAT noted in ( ) was incomplete. In those cases the TAT was estimated from the average monthly TAT. An @ after the TAT means that ASN130 was BCM'd at the end of its TAT. Its replacement will show up in inventory 30 days after the BCM date. The estimated inventory level available to VFA-125 on February 28 was 0. There were 3 ASN130s in the process of being repaired which were added to the inventory at the completion of their TAT. The inventory is estimated by adding any repairs of the day to the previous' days inventory then subtracting any demands that may occur during that day. A negative inventory denotes an accumulation of SCIR supply hours. This is where demand (failures) exceed supply (repairs) + the previous days inventory level. A (BCM Replaced) appearing to the right of the estimated inventory indicates that the replacement for the ASN130 which was BCM'd has been added to the inventory.

March

Day	Demands	TAT	Repairs	Estimated Inventory
1	0		1	1
2	2	9,10	0	-1
3	1	2	2	0
4	1	4	0	-1
5	0		1	0
6	1	(6)	0	-1
7	0		0	-1
8	1	1	1	-1
9	0		1	0
10	0		0	0
11	2	1,2	1	-1
12	0		3	2
13	0		1	3
14	0		0	3
15	0		0	3
16	0		0	3
17	0		0	3
18	2	5,6	0	1
19	1	5	0	0
20	0		1	1
21	0		0	1
22	0		0	1
23	2	3,3	1	0
24	2	2,5	2	0
25	3	1,6,27	0	-3
26	4	2,2,3,7	4	-3
27	1	4	0	-4
28	1	1	2	-3
29	0		3	0
30	3	3,3,3	0	-3
31	1	3	2	-2
	-----		-----	
	28 Failures		25 Repairs	

24 SCIR days (estimated)
576 SCIR hours (estimated)
583.1 SCIR hours (actual)

April

Day	Demands	TAT	Repairs	Estimated Inventory
1	2	1,1	0	-4
2	2	1,5	6	0
3	1	4	1	0
4	0		0	0
5	0		0	0
6	0		0	0
7	0		2	2
8	0		0	2
9	4	4,5,(5),10	0	-2
10	0		0	-2
11	0		0	-2
12	0		0	-2
13	1	7	1	-2
14	0		2	0
15	0		0	0
16	0		0	0
17	0		0	0
18	1	4	0	-1
19	1	6	1	-1
20	1	3	1	-1
21	0		1	0
22	0		1	1
23	1	5	1	1
24	0		0	1
25	0		1	2
26	0		0	2
27	1	2	0	1
28	0		1	2
29	1	7	1	2
30	1	3	0	1
	-----		-----	
	17 Failures		20 Repairs	

17 SCIR days (estimated)
408 SCIR hours (estimated)
449.8 SCIR hours (actual)

May

Day	Demands	TAT	Repairs	Estimated Inventory
1	1	3	0	0
2	0		0	0
3	0		1	1
4	0		1	2
5	1	10	0	1
6	1	5	1	1
7	1	11	0	0
8	0		0	0
9	0		0	0
10	0		0	0
11	1	5	1	0
12	0		0	0
13	3	1,1,8	0	-3
14	1	4	1	-3
15	1	7	2	-2
16	0		1	-1
17	0		0	-1
18	0		2	1
19	0		0	1
20	2	1,9	0	-1
21	0		2	1
22	0		1	2
23	0		0	2
24	0		0	2
25	0		0	2
26	1	2	0	1
27	1	2	0	0
28	0		1	1
29	0		2	3
30	0		0	3
31	0		0	3
	-----		-----	
	14 Failures		16 Repairs	

11 SCIR days (estimated)
264 SCIR hours (estimated)
257.4 SCIR hours (actual)

June

Day	Demands	TAT	Repairs	Estimated Inventory
1	1	8	0	2
2	1	14	0	1
3	0		0	1
4	1	4	0	0
5	1	6	0	-1
6	0		0	-1
7	0		0	-1
8	2	1,2	1	-2
9	0		2	0
10	0		1	1
11	0		1	2
12	0		0	2
13	0		0	2
14	0		0	2
15	0		0	2
16	0		1	3
17	0		0	3
18	1	4	0	2
19	1	8	0	1
20	0		0	1
21	0		0	1
22	1	1	1	1
23	0		1	2
24	1	6	0	1
25	0		0	1
26	2	3,17	0	-1
27	0		1	0
28	1	2	0	-1
29	0		0	0
30	0		2	2
	-----		-----	
	13 Failures		11 Repairs	

7 SCIR days (estimated)
168 SCIR hours (estimated)
194.3 SCIR hours (actual)

July

Day	Demands	TAT	Repairs	Estimated Inventory
1	0		0	2
2	1	21@	0	1
3	0		0	1
4	0		0	1
5	0		0	1
6	0		0	1
7	0		0	1
8	0		0	1
9	0		0	1
10	1	5	0	0
11	0		0	0
12	0		0	0
13	0		1	1
14	3	2,6,6	0	-2
15	0		1	-1
16	1	4	1	-1
17	0		0	-1
18	0		0	-1
19	0		0	-1
20	0		3	2
21	1	1	0	1
22	0		1	2
23	0		0	2
24	1	3	0	1
25	0		0	1
26	1	10@	0	0
27	1	1	1	0
28	0		1	1
29	1	5	0	0
30	0		0	0
31	0		0	0
	-----		-----	
	11 Failures		9 Repairs	

7 SCIR days (estimated)
168 SCIR hours (estimated)
171.5 SCIR hours (actual)

August

Day	Demands	TAT	Repairs	Estimated Inventory	
1	0		0	0	
2	0		0	0	
3	0		1	1	
4	0		0	1	
5	1	1	0	0	
6	1	(2)	1	0	
7	0		0	0	
8	0		1	1	
9	2	1,3	0	-1	
10	0		1	0	
11	0		0	0	
12	1	1	1	0	
13	0		1	1	
14	0		0	1	
15	0		0	1	
16	0		0	1	
17	0		0	1	
18	1	1	0	0	
19	3	(2),2,4	1	-2	
20	2	1,5	0	-4	
21	1	5@	3	-1	(BCM Replaced)
22	0		0	-1	
23	0		1	0	
24	0		0	0	
25	1	1	1	0	
26	3	1,(2),5	1	-2	
27	1	4	1	-2	
28	0		1	-1	
29	0		0	-1	
30	0		0	-1	
31	0		2	1	
	-----		-----		
	17 Failures		17 Repairs		

16 SCIR days (estimated)
384 SCIR hours (estimated)
324.5 SCIR hours (actual)

September

Day	Demands	TAT	Repairs	Estimated Inventory	
1	1	3	0	0	
2	1	6	0	-1	
3	0		0	-1	
4	0		1	0	
5	0		0	1	(BCM Replaced)
6	0		0	1	
7	0		0	1	
8	0		1	2	
9	0		0	2	
10	0		0	2	
11	0		0	2	
12	0		0	2	
13	0		0	2	
14	1	2	0	1	
15	0		0	1	
16	2	1,1	1	0	
17	1	1	2	1	
18	0		1	2	
19	0		0	2	
20	1	1	0	1	
21	0		1	2	
22	0		0	2	
23	0		0	3	(BCM Replaced)
24	0		0	3	
25	1	(2)	0	2	
26	0		0	2	
27	0		1	3	
28	0		0	3	
29	0		0	3	
30	0		0	3	
	-----		-----		
	8 Failures		8 Repairs		

2 SCIR days (estimated)
48 SCIR hours (estimated)
43.7 SCIR hours (actual)

October

Day	Demands	TAT	Repairs	Estimated Inventory
1	0		0	3
2	0		0	3
3	0		0	3
4	2	1,2	0	1
5	0		1	2
6	0		1	3
7	1	6	0	2
8	1	1	0	1
9	0		1	2
10	0		0	2
11	0		0	2
12	0		0	2
13	0		1	3
14	0		0	3
15	0		0	3
16	1	2	0	2
17	0		0	2
18	0		1	3
19	0		0	3
20	0		0	3
21	0		0	3
22	2	7,14	0	1
23	2	1,10	0	-1
24	0		1	0
25	0		0	0
26	0		0	0
27	1	1	0	-1
28	0		1	0
29	1	3	1	0
30	1	2	0	-1
31	0		0	-1
	-----		-----	
	12 Failures		8 Repairs	

4 SCIR days (estimated)
96 SCIR hours (estimated)
99.7 SCIR hours (actual)

APPENDIX B. IMUTS AVAILABILITY AND REPAIR TIME

The following data was collected to compare IMUTS availability to the average repair time on a weekly basis. The two IMUTS test benches were available a total of 280 hours a week. During two periods the IMUTS was down for AWP.

Week of	IMUTS hours down	IMUTS Availability	Average Repair time (days)
March 87			
2-8	6	97.9	1.0
9-15	6	97.9	1.5
16-22	0	100.0	0
23-29	0	100.0	1.3
April 87			
30-5	6	97.9	1.3
6-12	6	97.9	1.8
13-19	0	100.0	1.7
20-26	0	100.0	1.3
27-3	0	100.0	1.3
May 87			
4-10	0	100.0	1.0
11-17	140	50.0	3.0
18-24	96	67.5	1.5
25-31	0	100.0	1.3
June 87			
1-7	0	100.0	2.0
8-14	0	100.0	1.5
15-21	0	100.0	2.5
22-28	0	100.0	1.0
July 87			
29-5	0	100.0	1.0
6-12	0	100.0	1.0
13-19	0	100.0	4.0
20-26	0	100.0	1.0
27-2	0	100.0	0
August 87			
3-9	6	97.9	0
10-16	6	97.9	1.0
17-23	0	100.0	1.5
24-30	0	100.0	1.3
September 87			
31-6	0	100.0	1.0
7-13	72	74.3	1.0
14-20	96	65.7	1.0
21-27	0	100.0	0
October 87			
28-4	0	100.0	0
5-11	0	100.0	1.5
12-18	0	100.0	1.0
19-25	0	100.0	0

APPENDIX C. ASO COST INFORMATION

The part number, unit cost to purchase a new unit, the BCM cost which is the cost to repair the unit and the number of units NAS Lemoore is allowed are listed below. The number of units used in repair of the WRA are listed under Number Used. This was the number used over a five-month period.

PART NUMBER	UNIT COST	BCM COST	ALLOWANCE	Number Used
WRA				
8709010-1	118,000	14,400	11	
SRA				
879140-1	6,104	5,060	1	0
874366-5	8,821	2,690	1	0
879135-1	11,273	6,240	1	4
879100-1	2,584	2,520	2	0
874960-6	8,825	5,470	1	1
879090-2	2,207	2,140	1	0
879085-3	4,203	4,090	1	1
874905-2	10,757	3,240	1	0
874859-4	10,640	2,600	1	0
879060-4	3,385	2,610	0	0
879070-5	5,208	7,380	0	0
879120-2	6,433	6,260	0	0
854100-5	46,809	14,400	9	26

APPENDIX D. COMPUTER SIMULATION

The following is a listing of the Turbo Basic program for the simulation model. It was run on an IBM XT compatable computer.

```
'*************************************************************************
'*                                                                       *
'*  Programer: Chris Hase                          Date: Feb 1988        *
'*                                                                       *
'*  Language:  Turbo Basic Version 1.0                                   *
'*                                                                       *
'*  This program is a simulation that emulates failures of               *
'*  components, their induction into a repair center and then            *
'*  their return to inventory to be used again.                          *
'*    The turn around time (TAT) is also a geometric random              *
'*  variable. A bernoulli random variable is used in                     *
'*  deciding if a component is BCM'd. If the component is                *
'*  not in stock then SCIR days accumulate until an item is              *
'*  repaired and returned to inventory.                                  *
'*                                                                       *
'*  Input parameters:   initial stock level                              *
'*                      TAT                                              *
'*                                                                       *
'*  Output Number of failures for the month               (Failures) *
'*         Monthly failure rate                         (Failure rate) *
'*         Monthly average TAT                               (Ave TAT) *
'*         Monthly SCIR days                                  (M SCIR) *
'*         Monthly SCIR reduction due to 1 more in stock (SCIRED1) *
'*         Monthly SCIR reduction due to 2 more in stock (SCIRED2) *
'*         Monthly SCIR reduction due to 3 more in stock (SCIRED3) *
'*       8 Month Average TAT                                 (Ave TAT) *
'*       8 Month Total SCIR Days                    (Total SCIR Days) *
'*       8 Month Total BCMs                               (Total BCMs) *
'*       8 Month SCIR reduction due to 1 more in stock (Pool up 1) *
'*       8 Month SCIR reduction due to 2 more in stock (Pool up 2) *
'*       8 Month SCIR reduction due to 3 more in stock (Pool up 3) *
'*                                                                       *
'*************************************************************************


'*************************************************************************
'*                                                                       *
'*             Dimensioning Arrays                                       *
'*                                                                       *
'*************************************************************************


DIM randomno!(450)
DIM randomnol!(450)
$DYNAMIC
```

```
DIM inventory%(450)
DIM repairs%(450)
OPTION BASE 1
DIM daydemand%(450)
DIM bcm%(450)
DIM tat%(450)


'*************************************************************************
'*                                                                       *
'*              Input initial stock level and average TAT               *
'*                                                                       *
'*************************************************************************


   INPUT "Enter the initial stock level of the rotable pool ",dummy%
   INPUT "Enter the value for average TAT  ", avetat!
         p! = 1 / avetat!

   inventory%(0) = dummy%
   failrate! = 0.4894


'*************************************************************************
'*                                                                       *
'*              Set random seed to computer's clock                      *
'*                                                                       *
'*************************************************************************

RANDOMIZE TIMER


15  FOR I% = 1 to 450
        randomno!(I%) = RND
        u! = RND
        IF u! <= .02521 THEN bcm%(I%) = 1
        IF u! > .02521 THEN bcm%(I%) = 0
        randomno1!(I%) = RND
    NEXT I%

PRINT " "
PRINT "  Failures     Repairs    Inventory"

20  month% = 1
    demandcount% = 0
    counter% = 0
    scircount% = 0
    poolup1% = 0
    poolup2% = 0
    poolup3% = 0
    totalpoolup1% = 0
    totalpoolup2% = 0
    totalpoolup3% = 0
    monthcount% = 0
```

```
    tmonthtat% = 0
    monthfail% = 0


'******************************************************************************
'*                                                                            *
'*              Main loop for total number of days                            *
'*                                                                            *
'******************************************************************************

    FOR day% = 1 to 270
      dummy1% = INT(LOG(randomno!(day%)) / LOG (1-failrate!))
      IF dummy1% = 4 THEN dummy1% = 2
      IF dummy1% > 4 THEN dummy1% = 3
      daydemand%(day%) = dummy1%
      monthfail% = monthfail% + dummy1%
      counter% = counter% + 1

      IF daydemand%(day%) = 0 THEN GOTO 30
         FOR J% = 1 to daydemand%(day%)
           demandcount% = demandcount% + 1
           counter% = counter% + 1
tat%(demandcount%) = INT(LOG(randomno1!(demandcount%)) / LOG(1-p!))+1
           tmonthtat% = tmonthtat% + tat%(demandcount%)
           IF bcm%(counter%) = 1 THEN
              bcmcount% = bcmcount% + 1
              IF bcmcount% > 4 GOTO 25
                tat%(demandcount%) = tat%(demandcount%) + 30
    25     END IF
repairs%(day%+tat%(demandcount%))=repairs%(day%+tat%(demandcount%))+1
         NEXT J%
30 inventory%(day%)=inventory%(day%-1)+repairs%(day%)-daydemand%(day%)
      monthcount% = monthcount% + 1
      IF inventory%(day%) < 0 AND day% > 30 THEN
        dummy3% = ABS(inventory%(day%))
        scircount% = scircount% + dummy3%
        totalscircnt% = totalscircnt% + dummy3%
        poolup1% = poolup1% + 1
        totalpoolup1% = totalpoolup1% + 1
           IF dummy3% >= 2 THEN
              poolup2% = poolup2% + 1
              totalpoolup2% = totalpoolup2% + 1
           END IF
           IF dummy3% >= 3 THEN
              poolup3% = poolup3% + 1
              totalpoolup3% = totalpoolup3% + 1
           END IF
      END IF

'******************************************************************************
'*                                                                            *
'*              Output                                                        *
'*                                                                            *
'******************************************************************************
```

```
 PRINT "     "; daydemand%(day%),"    "; repairs%(day%), inventory%(day%)
      IF monthcount% > 29 THEN
         monthtat! = tmonthtat% / demandcount%
         IF day% > 30 THEN grandavetat! = grandavetat! + monthtat!
PRINT USING " Failures =##         Ave tat =##.##";_
         monthfail%,monthtat!
PRINT USING "M SCIR days =##  SCIRED1 ##  SCIRED2 ##  SCIRED3 ##";_
            scircount%; poolup1%; poolup2%; poolup3%
         monthcount% = 0
         scircount% = 0
         poolup1% = 0
         poolup2% = 0
         poolup3% = 0
         tmonthtat% = 0
         month% = month% + 1
         monthfail% = 0
         PRINT " "
         PRINT "TAT"
           FOR I% = 1 to demandcount%
             PRINT tat%(I%);
           NEXT I%
         PRINT " "
         PRINT " "
         PRINT "  Failures    Repairs     Inventory"
         demandcount% = 0
       END IF
    NEXT day%

PRINT USING "Ave TAT =##.##  Total SCIR days =###  Total BCM's =##";_
      grandavetat! / (month% - 2),totalscircnt%,bcmcount%
PRINT USING "Pool up 1 = ###      Pool up 2 =###     Pool up 3 =###";_
      totalpoolup1%; totalpoolup2%; totalpoolup3%


PRINT " "


'*********************************************************************
'*                                                                   *
'*             Prompts to rerun program and change random numbers    *
'*                                                                   *
'*********************************************************************


INPUT "Do you wish to run this program again (y/n)? ", rerun$
   runagain% = ASC(rerun$)
   IF runagain% = 78 THEN GOTO 99
   IF runagain% = 110 THEN GOTO 99
   inventory%(0) = dummy1%


PRINT " "

INPUT "Do you wish to enter a new repair rate (y/n)? ", rerun2$
   runagain2% = ASC(rerun2$)
   IF runagain2% = 89 THEN
```

```
      INPUT "Enter the new value for average TAT ",avetat!
      p! = 1 / avetat!
    END IF
    IF runagain2% = 121 THEN
      INPUT "Enter the new value for average TAT ",avetat!
      p! = 1 / avetat!
    END IF

    FOR I% = 1 to 450
      repairs%(I%) = 0
      inventory%(I%) = 0
    NEXT I%

    inventory%(0) = dummy%
    bcmcount% = 0
    scircount% = 0
    poolup1% = 0
    poolup2% = 0
    poolup3% = 0
    totalscircnt% = 0
    totalpoolup1% = 0
    totalpoolup2% = 0
    totalpoolup3% = 0
    grandavetat! = 0

INPUT "Do you wish to generate a new set of random numbers (y/n)? ",_
        rerun4$
    runagain4% = ASC(rerun4$)
    IF runagain4% = 89 THEN GOTO 15
    IF runagain4% = 121 THEN GOTO 15

    GOTO 20

99 END
```

APPENDIX E. SAMPLE COMPUTER OUTPUT

The following is a sample computer output for the last 30 days of a nine-month run. Only statistics were kept for the last eight months. This was done to allow the demands, repairs and inventory to reach a steady state before the statistics were computed. The columns list the number of failures, repairs and inventory level on each day of the month. All months were 30 days long. Statistics computed for the month included number of failures, failure rate, and average TAT. M SCIR days is the number of units where demand (failures) exceeded supply (repairs). SCIRED1 would be the number of SCIR days that would be eliminated as a result of one more unit in the pool allowance level. SCIRED2 and SCIRED3 are the additional reductions in SCIR days as a result of two and three more units in the pool allowance level. Statistics for the entire eight-months are shown at the end of this appendix and include average TAT, total SCIR days, total BCMs and total SCIR reductions as a result on one, two and three more units in the pool.

Failures	Repairs	Inventory
0	0	2
3	0	-1
0	0	-1
1	3	1
0	0	1
1	0	0
0	1	1
1	0	0
0	0	0
0	1	1
0	2	3
0	0	3
1	0	2
0	0	2
0	0	2
0	0	2
0	0	2
0	0	2
3	0	-1
0	1	0
1	1	0
0	1	1
1	0	0
0	0	0
1	0	-1
1	1	-1
0	1	0
2	0	-2
0	0	-2
0	0	-2

Failures = 16 Ave TAT = 5.94
M SCIR days = 11 SCIRED1 = 8 SCIRED2 = 3 SCIRED3 = 0

TAT For failed items this month
2 2 5 6 5 3 14 1 16 2 1 9 1 17 8 3

Statistics for the eight-month run

Ave TAT = 5.49 Total SCIR days = 137 Total BCMs = 1
Pool up 1 = 78 Pool up 2 = 35 Pool up 3 = 15

APPENDIX F. SENSITIVITY ANALYSIS RESULTS

A run represents 144 monthly computer simulations that used the same average failure rate as the original data. Only the TAT and inventory levels were adjusted. SCIR is the number of days the ASN130 was out of stock. Column Up 1 is the reduction of SCIR days due to an increase of one ASN130 in the pool allowance. Columns Up2 and Up3 are the additional reductions in SCIR days due to increases in the pool allowance of two and three ASN130s. Column SCIR1 is the total SCIR days as a result of increasing the pool allowance by one ASN130. Columns SCIR2 and SCIR3 are the total SCIR days as a result of increasing the pool allowance by two and three ASN130s.

Even after reaching a steady state after running 144 monthly computer simulations there were slight variations in the average TAT as compared to the input value due to variances caused by the geometric distribution. On the last page of this appendix the data is averaged from the five sets of runs. Column Ave TAT is the average TAT from all five runs. Column Ave S is the average SCIR days from those runs. Column Ave S1 is the average SCIR days from those five runs as a result of increasing the pool allowance by one ASN130. Columns Ave S2 and Ave S3 are the average SCIR days from those five runs as a result of increasing the pool allowance by two and three ASN130s. These values are plotted in Figure 6.

Run	TAT	SCIR	Up1	Up2	Up3	SCIR1	SCIR2	SCIR3
1	8.96	419	142	96	63	277	181	118
	8.47	374	133	89	54	241	152	98
	7.99	328	123	76	50	205	129	79
	7.49	292	111	70	47	181	111	64
	6.99	249	97	61	43	152	91	48
	6.52	216	88	56	36	128	72	36
	6.03	180	76	51	28	104	53	25
	5.50	146	68	43	19	78	35	16
	5.03	125	64	36	14	61	25	11
	4.48	94	51	28	9	43	15	6
	4.35	87	49	26	7	38	12	5
	4.02	69	45	18	4	24	6	2
	3.52	46	30	14	2	16	2	0
	2.96	32	22	9	1	10	1	0
	2.51	21	14	6	1	7	1	0
	2.02	17	11	6	0	6	0	0
	1.50	5	4	1	0	1	0	0
	1.00	0	0	0	0	0	0	0

Run	TAT	SCIR	Up1	Up2	Up3	SCIR1	SCIR2	SCIR3
2	9.03	402	167	113	62	235	122	60
	8.52	356	154	99	51	202	103	52
	8.02	315	139	85	45	176	91	46
	7.52	277	124	77	37	153	76	39
	7.00	241	113	66	30	128	62	32
	6.49	205	105	49	27	100	51	24
	6.01	177	95	42	23	82	40	17
	5.50	146	81	35	17	65	30	13
	4.98	117	65	28	14	52	24	10
	4.49	96	54	25	12	42	17	5
	4.38	91	52	23	12	39	16	4
	3.98	70	43	16	9	27	11	2
	3.47	52	33	11	8	19	8	0
	3.02	36	23	9	4	13	4	0
	2.53	23	16	5	2	7	2	0
	1.98	15	10	3	2	5	2	0
	1.53	10	8	2	0	2	0	0
	1.03	5	4	1	0	1	0	0
3	9.03	450	157	106	73	293	187	114
	8.48	399	140	100	66	259	159	93
	8.00	358	133	92	58	225	133	75
	7.52	318	122	87	49	196	109	60
	6.97	274	112	74	41	162	88	47
	6.49	238	99	69	34	139	70	36
	6.03	208	93	60	29	115	55	26
	5.50	176	85	53	24	91	38	14
	4.99	144	76	41	18	68	27	9
	4.51	115	60	36	14	55	19	5
	4.34	106	56	32	13	50	18	5
	3.98	87	48	26	9	39	13	4
	3.50	67	38	21	6	29	8	2
	3.01	47	31	11	3	16	5	2
	2.47	34	21	9	3	13	4	1
	1.97	17	12	4	1	5	1	0
	1.53	11	9	1	1	2	1	0
	1.00	4	4	0	0	0	0	0

Run	TAT	SCIR	Up1	Up2	Up3	SCIR1	SCIR2	SCIR3
4	8.99	358	150	95	51	208	113	62
	8.52	319	138	85	44	181	96	52
	7.97	276	124	74	36	152	78	42
	7.48	243	110	68	31	133	65	34
	6.97	210	101	58	27	109	51	24
	6.48	183	92	46	22	91	45	23
	6.00	153	81	36	20	72	36	16
	5.51	127	67	32	14	60	28	14
	4.97	101	57	24	12	44	20	8
	4.52	85	48	22	10	37	15	5
	4.37	78	45	20	9	33	13	4
	4.01	66	40	16	7	26	10	3
	3.47	43	28	10	5	15	5	0
	2.96	28	19	7	2	9	2	0
	2.48	16	13	3	0	3	0	0
	1.98	8	8	0	0	0	0	0
	1.50	4	4	0	0	0	0	0
	1.02	1	1	0	0	0	0	0
5	9.02	433	169	110	69	264	154	85
	8.55	389	157	100	61	232	132	71
	8.03	341	148	88	53	193	105	52
	7.51	300	140	75	48	160	85	37
	7.03	256	127	65	37	129	64	27
	6.52	212	110	55	28	102	47	19
	5.97	176	94	44	24	82	38	14
	5.49	137	78	35	15	59	24	9
	5.01	115	67	31	11	48	17	6
	4.47	90	55	24	8	35	11	3
	4.33	84	50	24	8	34	10	2
	3.98	64	40	15	7	24	9	2
	3.53	47	32	9	4	15	6	2
	3.02	34	23	8	2	11	3	1
	2.52	21	14	5	1	7	2	1
	1.96	12	7	4	1	5	1	0
	1.47	4	4	0	0	0	0	0
	1.00	0	0	0	0	0	0	0

Results From the Average of Five Runs

Ave TAT	Ave S	Ave S1	Ave S2	Ave S3
9.01	412.4	255.4	151.4	87.8
8.51	367.4	223.0	128.4	73.2
8.00	323.6	190.2	107.2	58.8
7.50	286.0	164.6	89.2	46.8
6.99	246.0	136.0	71.2	35.6
6.50	210.8	112.0	57.0	27.6
6.01	178.8	91.0	44.4	19.6
5.50	146.4	70.6	31.0	13.2
5.00	120.4	54.6	22.6	8.8
4.49	96.0	42.4	15.4	4.8
4.35	89.2	38.8	13.8	4.0
3.99	71.2	28.0	9.8	2.6
3.50	51.0	18.8	5.8	0.8
2.99	35.4	11.8	3.0	0.6
2.50	23.0	7.4	1.8	0.4
1.98	13.8	4.2	0.8	0.0
1.51	6.8	1.0	0.2	0.0
1.01	2.0	0.2	0.0	0.0

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